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A Relationship Between SSM/I Brightness Temperatures and Earth Surface Emissivities at 91 and 150 GHz

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The Special Sensor Microwave Water Vapor Sounder (SSM/T-2) is onboard the Defense Meteorological Satellite Program (DMSP) F-11 satellite and consists of five channels: three located along the 183 GHz water vapor absorption line, one on the wing of this line at 150 GHz, and a 91 GHz window channel. Also onboard this satellite is the Special Sensor Microwave/Imager (SSM/I) which has seven channels - 19, 37, and 85 GHz vertical and horizontal polarizations, and 22 GHz vertical polarization. Estimation of surface emissivities at 91 and 150 GHz is a key component in the SSM/T-2 water vapor profile retrieval algorithm. This study relates 91 and 150 GHz emissivity values, retrieved from a radiative transfer model using collocated SSM/T-2 brightness temperature measurements and radiosonde-measured atmospheric profiles, to SSM/T-2 and SSM/I brightness temperature measurements. Results suggest the possible use of SSM/I brightness temperature measurements for estimation of surface emissivities at 91 and 150 GHz.

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A RELATIONSHIP BETWEEN SSM/I BRIGHTNESS TEMPERATURES AND EARTH SURFACE EMISSIVITIES AT 91 AND 150 GHZ

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1. INTRODUCTION

Global water vapor profile measurements are necessary input data for numerical weather and climate prediction models. The Special Sensor Microwave Water Vapor Sounder (SSM/T-2), designed to measure water vapor profiles, is onboard the Defense Meteorological Satellite Program (DMSP) F-11 satellite and consists of five channels: three located along the 183 GHz water vapor absorption line, one on the wing of this line at 150 GHz, and a 91 GHz window channel. In general, there is significant sensitivity to the surface of the earth only for brightness temperature (TB) measurements at the two lower SSM/T-2 frequencies. Estimation of surface emissivities at 91 and 150 GHz is a key component in the SSM/T-2 water vapor profile retrieval algorithm. (See Falcone et al., 1992 for more details.)

This study relates surface emissivity values at 91 and 150 GHz, retrieved from a radiative transfer model using collocated SSM/T-2 TB measurements and radiosonde-measured atmospheric profiles, to SSM/T-2 and SSM/I (Special Sensor Microwave/Imager) TB measurements. There is an SSM/I instrument on the same satellite as the SSM/T-2. The SSM/I, designed to measure various surface and atmospheric parameters, has seven channels - 19, 37, and 85 GHz vertical and horizontal polarizations (19V&H, 37V&H, 85V&H), and 22 GHz vertical polarization (22V) (Hollinger et al., 1987). The possible use of SSM/I and SSM/T-2 TB measurements for estimation of 91 and 150 GHz emissivities is examined.

2. SURFACE EMISSIVITIES

The cloud-free cases from the SSM/T-2 Calibration study (Falcone et al., 1992) global data set of collocated SSM/T-2 TB and radiosonde moisture and temperature profile measurements were used to retrieve surface emissivities at 91 and 150 GHz (Felde and Pickle, 1994). Emissivities were calculated by inputting the measured profiles into a radiative transfer model (Eyre and Woolf, 1988) (assumed surface air and skin temperatures were equal) and iterating over the possible range of emissivity values (i.e., 0 to 1) until the model output TB equaled the measured SSM/T-2 TB. They found the mean 91 GHz emissivity value to be 0.61 for water surfaces, 0.78 for coastal surfaces (mixture of land and water in the SSM/T-2's footprint), 0.92 for land surfaces, and 0.86 for all three surface types combined. Mean 150 GHz emissivity values followed a similar pattern for the different surface types but were slightly smaller.

3. EMISSIVITIES AND SSM/T-2 TB'S

The retrieved 91 and 150 GHz emissivities discussed above were compared to the corresponding 91 and 150 GHz TB's in a linear correlation analysis. Correlation coefficient (r) values are given in Table 1 for three surface categories - coast, land, all (coast and land cases combined) and three water vapor categories defined using total precipitable water (TPW) values calculated from the radiosonde profiles. The TPW category of 0 – 75 kg/m^2 includes all cases in this data set, while the other two TPW categories each excludes a different range of the more moist atmospheric cases. Only 21 water surface cases were available in this data set and thus were not included in the analysis.

The r values given in Table 1 for 91 GHz emissivity vs. 91 GHz TB increase in each of the three surface categories as one considers just the drier atmospheric cases (i.e., range of TPW decreases). This is also true for the other emissivity and TB comparisons. Thus, there is a detrimental influence of larger amounts of water vapor on the strength of the linear relationship

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Table 1. Correlation coefficients (r) for emissivity vs. TB at 91 and 150 GHz for three TPW categories. (* $p > .10$; □ $.01 < p < .05$; $p < .01$ for all other r values.)

TPW (kg/m^2)	0 - 75			0 - 40			0 - 20		
Surface	Coast	Land	All	Coast	Land	All	Coast	Land	All
91 GHz Emissivity vs. TB									
TB: 91	.31	.76	.64	.54	.82	.79	.67	.87	.85
150	.02*	.75	.38	.16□	.79	.54	.29	.84	.70
Mean TPW	23.9	19.1	20.7	15.6	17.1	16.7	10.5	11.3	11.1
# cases	241	488	729	183	460	643	135	299	434
150 GHz Emissivity vs. TB									
TB: 91	-.09*	.28	.26	.45	.42	.53	.67	.79	.81
150	-.14□	.38	.19	.18□	.51	.45	.40	.80	.66
Mean TPW	23.4	18.4	20.1	15.3	16.7	16.3	10.5	11.3	11.0
# cases	235	464	699	181	442	623	135	294	429

between emissivities and TB's at 91 and 150 GHz.

For a given emissivity and TB pair and TPW category, the r value for the land category is generally larger than for the coast category. Coastal surfaces (i.e., mixture of water and land) have smaller emissivities than land surfaces. A lower emissivity means less upward emission from the surface and also more reflection (reflectance = 1 − emissivity) of downwelling atmospheric radiation back upward. Thus, there is a weaker linear relationship between TB and surface emissivity for lower emissivity surfaces.

Correlation coefficients were also calculated for emissivities at 91 and 150 GHz vs. TB for each of the three 183 GHz channels for the same surface and TPW categories shown in Table 1. The computed r values for the "all" surface category for each of the three TPW categories were less than 0.5 with the majority being less than 0.25. This indicates a weak relationship if any at these frequencies which makes sense because in general the three 183 GHz channels have little or no sensitivity to the earth's surface since they all have weighting functions that peak above the surface.

A small subset of the data set used in the above analysis was extracted and augmented with SSM/I TB data. This subset consists of six land (Fort Nelson - Canada; Caribou, Dodge City, North Little Rock, Monett, and Midland - U.S.) and six coastal (Long Kesh and Aughton - U.K.; Gagetown - Canada; Wallops Island, Buffalo, and Portland, ME - U.S.) radiosonde station locations. The correlation coefficients for emissivities vs. TB's at 91 and 150 GHz for this subset of data is given in Table 2 for surface categories of coast, land, and all. Maximum TPW values for each surface category are also given and indicate relatively dry atmospheric profiles. Correlation coefficients for the cases from the original data set having approximately the same TPW range as the subset (TPW ≤ 25 kg/m^2) are given in parentheses for comparative purposes.

In general, r values for a given set of emissivity, TB, and surface category are larger for the subset compared to the original data set. Better correlation results for the subset are probably due to the greater range and variability of surface and atmospheric conditions for the larger data set. Even though TPW values are approximately the same for the two data sets, the variability of the vertical distribution of temperature and water vapor is larger for

Table 2. Correlation coefficients (r) for emissivity vs. TB at 91 and 150 GHz for a small and large data set with similar TPW values. ($p < .01$ for all r values.)

Surface	Coast	Land	All
Max TPW (kg/m^2)	19(25)	32(25)	32(25)
91 GHz Emissivity vs. TB			
TB: 91	.92(.67)	.90(.85)	.95(.85)
150	.68(.28)	.77(.82)	.79(.64)
# cases	17(149)	14(356)	31(505)
150 GHz Emissivity vs. TB			
TB: 91	.89(.67)	.86(.64)	.90(.73)
150	.68(.39)	.83(.68)	.78(.63)
# cases	17(149)	14(348)	31(497)

the main data set. However, the two data sets follow the same pattern of the 91 GHz TB's having a stronger linear association (larger r values) with emissivities at 91 and 150 GHz than that for the 150 GHz TB's. This occurs because there is more surface information in TB's at the 91 GHz window channel than at the 150 GHz channel which is on the wing of the 183 GHz water vapor absorption line.

4. EMISSIVITIES AND SSM/I TB'S

Correlation results between 91 and 150 GHz emissivities and TB's for each of the seven channels of the SSM/I, and also TB's for the 91 and 150 GHz channels of the SSM/T-2, for the data subset described above are presented in Table 3. The SSM/I data have finer spatial resolution than the SSM/T-2 data and so spatially averaged SSM/I TB's over the SSM/T-2 footprints were used in this analysis. The r values indicate a strong positive linear relationship between emissivity at each of the

Table 3. Correlation coefficients (r) for 91 and 150 GHz emissivities vs. SSM/I and SSM/T-2 TB's. ($p < .01$ for all r values.)

Surface	Coast	Land	All
Mean TPW (kg/m^2)	12.6	22.9	17.2
# cases	17	14	31
91 GHz Emissivity vs. TB			
TB: 19V	.97	.90	.98
19H	.97	.92	.98
22V	.96	.86	.97
37V	.96	.87	.97
37H	.96	.92	.97
85V	.69	.80	.82
85H	.96	.88	.97
91	.92	.90	.95
150	.68	.77	.79
150 GHz Emissivity vs. TB			
TB: 19V	.91	.87	.92
19H	.91	.87	.91
22V	.90	.85	.91
37V	.91	.86	.92
37H	.90	.89	.91
85V	.70	.75	.79
85H	.90	.80	.92
91	.89	.86	.90
150	.68	.83	.78

two frequencies, 91 and 150 GHz, and TB's at all the microwave channels listed. All r values are 0.85 and greater, except those for 85V and 150 GHz TB's (and also for 85H TB vs. 150 GHz emissivity for the land category). The reason for weaker correlations for 85V TB's is not obvious. The 85V channel is the SSM/I channel most sensitive to clouds (Hollinger et al., 1991) and thus it appears that cloudiness was present within some of the microwave footprints closest to a given radiosonde station. The radiosonde-measured atmospheric profiles having all levels unsaturated (relative humidity $< 95\%$) were assumed to indicate cloud-free conditions. But the existence of some clouds is possible for relative humidity $< 95\%$. Also, even if it is cloud-free along the path traveled by a radiosonde, this does not guarantee clear conditions over the large spatial area covered by the microwave footprint closest to the radiosonde station.

A plot of 91 GHz emissivities vs. collocated 19V TB's for the "all" surface category is given in Fig. 1. The linear regression line is included in the plot. A similar plot of 150 GHz emissivities vs. 19V TB's is given in Fig. 2. The land surface category cases generally have higher emissivity and TB values than the coastal surface category cases in both plots. More scatter about the regression line is evident at 150 GHz than at 91 GHz.

5. CONCLUSIONS

Results indicate a strong positive linear relationship ($r \geq 0.85$) between both 91 and 150 GHz emissivities and TB's for each of the seven SSM/I channels (except for the 85V channel) and also for the 91 GHz SSM/T-2 channel for both coastal and land surfaces for a small data set containing cloud-free and dry atmospheric cases (TPW values $< \sim 30$ kg/m^2). However, results from a larger and more diverse cloud-free data set of 91 and 150 GHz TB's and emissivities show the degrading effect of larger amounts of water vapor on the strength of the linear relationship between emissivity and TB's at 91 and 150 GHz. It is expected that larger amounts of water vapor would also degrade the relationship between SSM/I TB's and 91 and 150 GHz emissivities but to a much lesser extent at the lower frequency channels (19 and 37 GHz, but not 22 GHz because there is a weak water vapor resonance line at this frequency) which

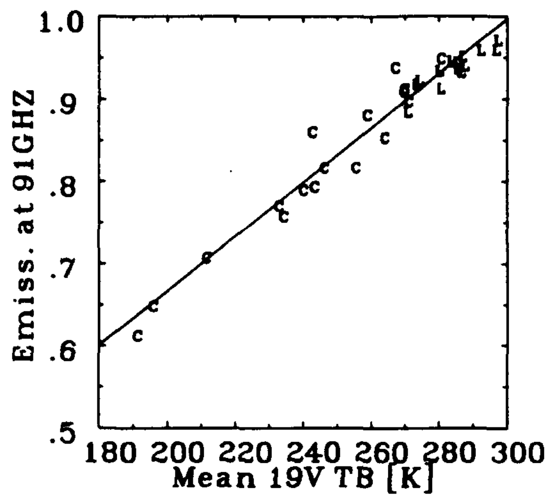

Fig. 1. Scatter diagram of 91 GHz emissivities vs. spatial mean 19V TB's over the 91 GHz footprint for all cases (L = land, C = coast). [Regression line equation: $\epsilon(91) = .0033 \times TB(19V) + .0071$ ($r = .98$, $n = 31$).]

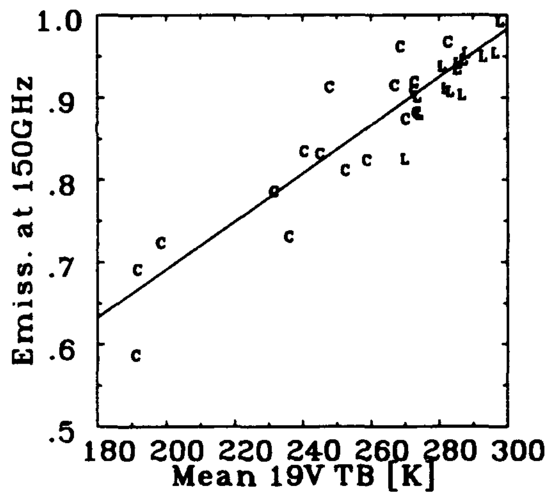

Fig. 2. Scatter diagram of 150 GHz emissivities vs. spatial mean 19V TB's over the 150 GHz footprint for all cases (L = land, C = coast). [Regression line equation: $\epsilon(150) = .0029 \times TB(19V) + .1072$ ($r = .92$, $n = 31$).]

have greater atmospheric transmissivity (in the absence of precipitation or thick clouds) compared to 85, 91, and 150 GHz. A sufficient amount of the surface component might be present at 19 and/or 37 GHz to allow for a useful relationship between SSM/I TB's and 91 and 150 GHz emissivities under some types of cloudy conditions. This study demonstrates the potential of using SSM/I TB's to estimate surface emissivities at 91 and 150 GHz which is a key element in the SSM/T-2 water vapor profile retrieval algorithm. Additional study is required to confirm this potential.

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